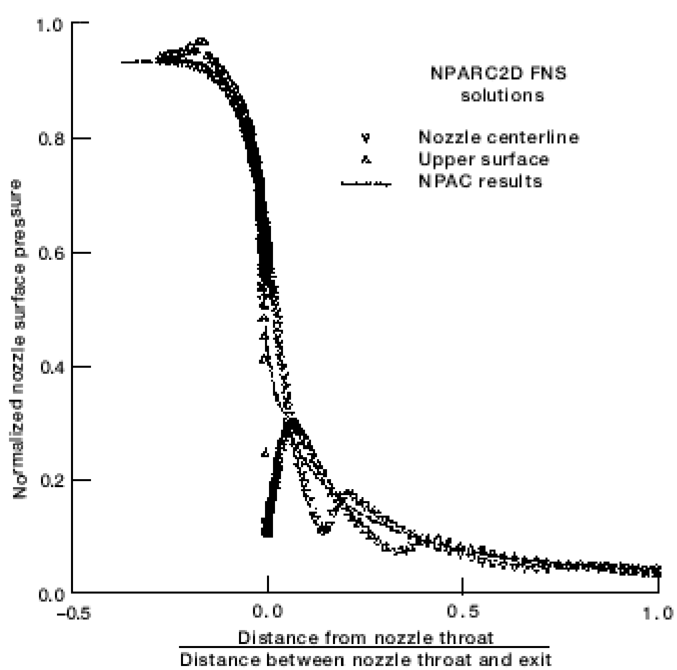
Conceptual Design Method Developed for Advanced Propulsion Nozzles

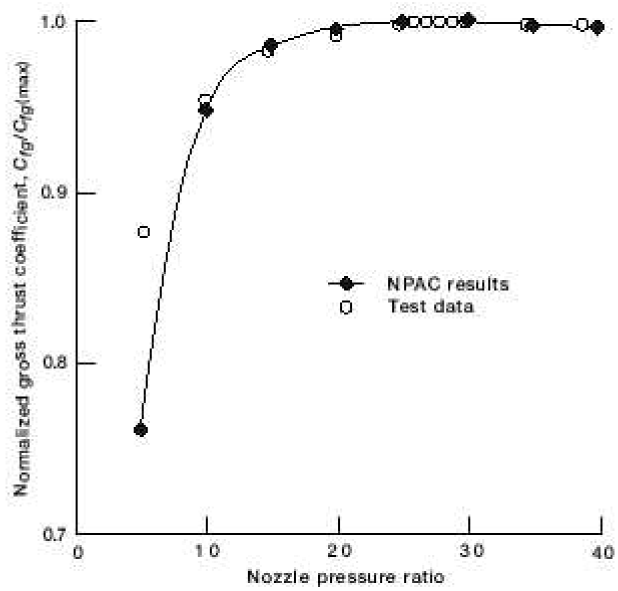
As part of a contract with the NASA Lewis Research Center, a simple, accurate method of predicting the performance characteristics of a nozzle design has been developed for use in conceptual design studies. The Nozzle Performance Analysis Code (NPAC) can predict the on- and off-design performance of axisymmetric or two-dimensional convergent and convergent-divergent nozzle geometries. NPAC accounts for the effects of overexpansion or underexpansion, flow divergence, wall friction, heat transfer, and small mass addition or loss across surfaces when the nozzle gross thrust and gross thrust coefficient are being computed. NPAC can be used to predict the performance of a given nozzle design or to develop a preliminary nozzle system design for subsequent analysis.

The input required by NPAC consists of a simple geometry definition of the nozzle surfaces, the location of key nozzle stations (entrance, throat, exit), and the nozzle entrance flow properties. NPAC performs three analysis "passes" on the nozzle geometry. First, an isentropic control volume analysis is performed to determine the gross thrust and gross thrust coefficient of the nozzle. During the second analysis pass, the skin friction and heat transfer losses are computed. The third analysis pass couples the effects of wall shear and heat transfer with the initial internal nozzle flow solutions to produce a system of equations that is solved at steps along the nozzle geometry. Small mass additions or losses, such as those resulting from leakage or bleed flow, can be included in the model at specified geometric sections. A final correction is made to account for divergence losses that are incurred if the nozzle exit flow is not purely axial.



Surface pressure comparison of NPAC results with a full Navier-Stokes (FNS) flow field *solution for a two-dimensional test model nozzle.*

NPAC has been validated with various nozzle test data. In addition, NPAC results have been compared with computational fluid dynamics (CFD) solutions. Results are presented here for a two-dimensional nozzle test model. The preceding figure compares the nozzle surface pressure distribution computed by NPAC with that computed by a CFD solution. The NPAC solution corresponds very closely to an average of the upper and centerline surface solutions from the CFD analysis. The following figure compares the normalized gross thrust coefficient C_{fg} computed for this nozzle by NPAC with those from model test data. This figure indicates good agreement between the computed and measured values of C_{fg} over most of the range of nozzle pressure ratios. The numbers diverge at lower nozzle pressure ratios, however. This is a result of the separation that can result inside a greatly overexpanded nozzle. NPAC does not include the ability to model this separation, and will, therefore, predict a C_{fg} significantly lower than that seen in actual nozzles.



Comparison of normalized gross thrust coefficient from NPAC results with that from experimental data for a two-dimensional test model nozzle at various nozzle pressure ratios.

The Nozzle Performance Analysis Code is a simple method for predicting nozzle performance. NPAC enables nozzle trade and design studies to be performed quickly and accurately. It is, therefore, a valuable tool in the conceptual design process of advanced propulsion systems.

Lewis contact: Shari-Beth Nadell, (216) 977-7035, Shari-Beth.Nadell@grc.nasa.gov
Authors: Shari-Beth Nadell and Paul J. Barnhart
Headquarters program office: OASTT
Programs/Projects: AST, HSR